CHAPTER 4

PILOT-SCALE TESTS

4-1. Introduction. With respect to pilot-scale testing, this EM supplements and updates detailed discussions of pilot testing found in the following references: EM 1110-1-4001, Soil Vapor Extraction and Bioventing; Air Force Center for Environmental Excellence Test Plan and Technical Protocol for Bioslurping; and USEPA 600/R-96/031, UST Corrective Action Technologies: Engineering Design of Free Product Recovery Systems. These documents each provide substantial guidance related to bench- and pilot-scale testing. All MPE pilot testing should be planned and carried out in accordance with the requirements of EM 200-1-2 and 200-1-3.

4-2. Pilot Testing Guidance.

a. Objectives. The primary objectives of typical MPE pilot tests are listed as follows:

(1) Mass Removal. A pilot test can be viewed as a demonstration that MPE can accomplish removal of contaminant mass at sufficient rates to demonstrate that if carried out over a longer time period, MPE has the potential to achieve significant remediation. This objective must be considered in the context of the initial concentrations versus the remedial goals, and the length of the pilot test versus the length of the remediation. It can be expected that rates of mass removal will decline sharply over time; thus, the rate observed during the pilot test should not be expected to continue over a long period. Indeed, once the most readily-extracted fraction of the contaminant mass is removed by advection, the diffusion-limited mass transfer that ensues typically causes contaminant mass removal to taper off to an asymptotic level.

(2) Zone of Influence. A properly designed MPE pilot test will provide indications of the vadose and saturated zone response to the application of vacuum. The effective zone of influence can be discerned through monitoring a variety of data, including pressures in soil gas monitoring points, piezometric heads in monitoring wells and drive-point piezometers, moisture content via neutron probe access tubes, and tracer velocities/capture during injection of gaseous and/or liquid tracers.

(3) Subsurface Soil Properties/Parameters. MPE pilot tests provide information on the nature and variability of site-specific subsurface parameters, such as air permeability, hydraulic conductivity, soil moisture retention, and contaminant distribution.

(4) Discharge Concentrations/Design Parameters. MPE pilot testing provides designers with an indication of the initial levels of contaminants in extracted gas and liquid. These data may be used to specify treatment equipment and to prepare applications for discharge permits. It must be remembered, however, that the early concentrations seen during pilot tests are usually the highest that will be seen over a longer term remediation, unless significant desaturation is anticipated to occur over time, which may open pathways for air movement and improve mass transfer. In finer-textured, lower-permeability settings, however, substantial mass removal from desaturated regions may not be a realistic expectation (Baker and Groher 1998).

(5) Cost Estimates. MPE pilot tests can help refine cost estimates for full-scale system implementation and operation. Cost estimates based on pilot tests may, however, include extra costs not necessarily related to full-scale application (e.g., testing, analytical, ancillary equipment, inappropriately sized equipment).

b. Limitations of Pilot Studies.

(1) One *cannot* expect to achieve remedial goals (RGs) or to establish long-term trends in mass removal during a typical short-term MPE pilot test.

(2) One *can* expect to determine whether appropriate physical conditions can be established that will, over time, be conducive to achievement of RGs.

(3) Although mass removal may be included as a test objective, prior specification of a percentage removal should be avoided unless such a goal has already been established based on leaching studies, fate and transport modeling, and/or risk assessment. For example, although >90% mass removal may not be realistically achievable even within those zones targeted for MPE, leaving a certain lesser percentage of the contaminant mass in the subsurface following active remediation may still be sufficiently protective, if its potential contribution to groundwater contamination is low enough to be consistent with RGs. Quantifying the initial contaminant mass in place is usually difficult, due to sampling losses/errors and inherent spatial variability in contaminant distribution. Thus, attainment of a specified percentage mass removal can be very difficult to confirm, and may not constitute a reliable pilot test objective.

c. Preparation and Permits. Prior to performance of pilot testing, certain preparations must be made. A work plan of activities to be performed should be prepared for involved parties prior to conducting the pilot test. The work plan is vital for specifying test objectives, the range of operating conditions, and parameters to be monitored, including the locations, methods, and frequency of measurements to be taken. The work plan often is reviewed by regulatory agencies and forms the basis for the contractor scope of services. A Site Safety and Health Plan (SSHP) is required prior to conducting the work to assure safety of all on-site workers. A detailed discussion of safety is included in paragraph 9-4. A schedule showing critical tasks and the various phases of the work should be included. A materials list for necessary equipment and supplies should also be prepared. Necessary permits (paragraph 9-2b), as applicable, must also be obtained for pilot system installation and discharge streams. Permitting requirements will vary depending on testing location, but may include electrical and mechanical permits for system installation, and air and water discharge permits.

d. Equipment. Most pilot systems are installed for temporary operation only. Compact equipment and treatment units that can be easily connected are extremely beneficial, especially when operating within a high traffic area with limited access and available space (e.g., gasoline station, loading dock). In some cases, however, pilot testing may represent the first phase of a staged implementation at the site. In this case, it may be desirable to oversize the equipment and equipment shelters in anticipation of future phases of the project.

(1) Extraction Wells. During pilot testing, existing monitoring wells may be used as extraction wells if they are in proper condition (e.g., well casing not cracked; well seal and well head intact) and appropriate to the task (e.g.,

sufficient diameter; and with properly positioned screen interval). Otherwise, new wells must be installed. Materials of well construction must be compatible with the contaminants present. Note, for example, that PVC is not compatible with most chlorinated solvents when they are present as pure product. PVC piping can, however be used with chlorinated solvents when dissolved in water at concentrations in the parts per million range. Many electrical submersible pumps require a minimum well diameter of 10 cm (4 in). Figures 4-1 and 4-2 show typical extraction well set-ups for DPE and TPE, respectively.

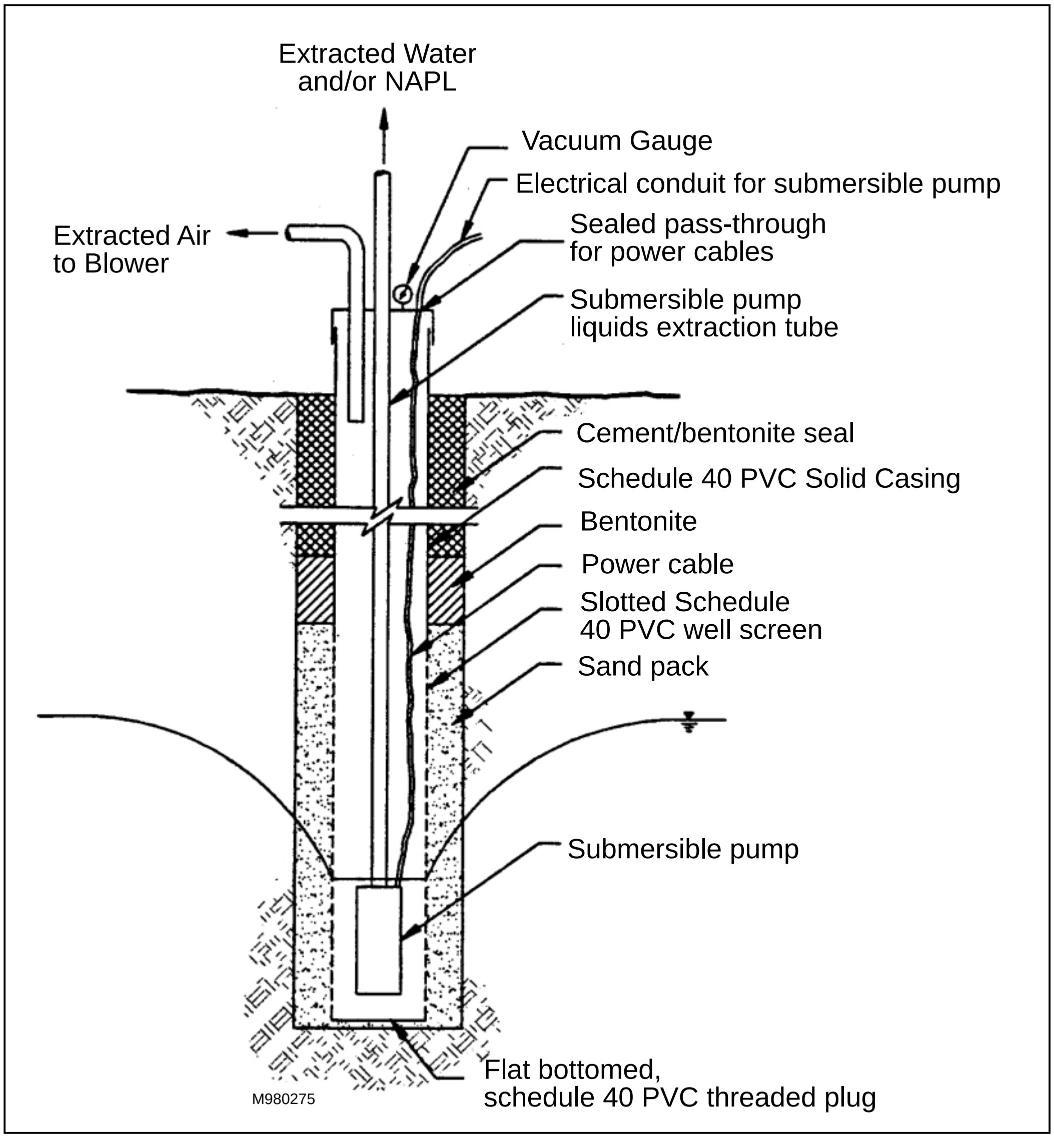


Figure 4-1. Dual-Phase Extraction Well. (After EPA 1995)

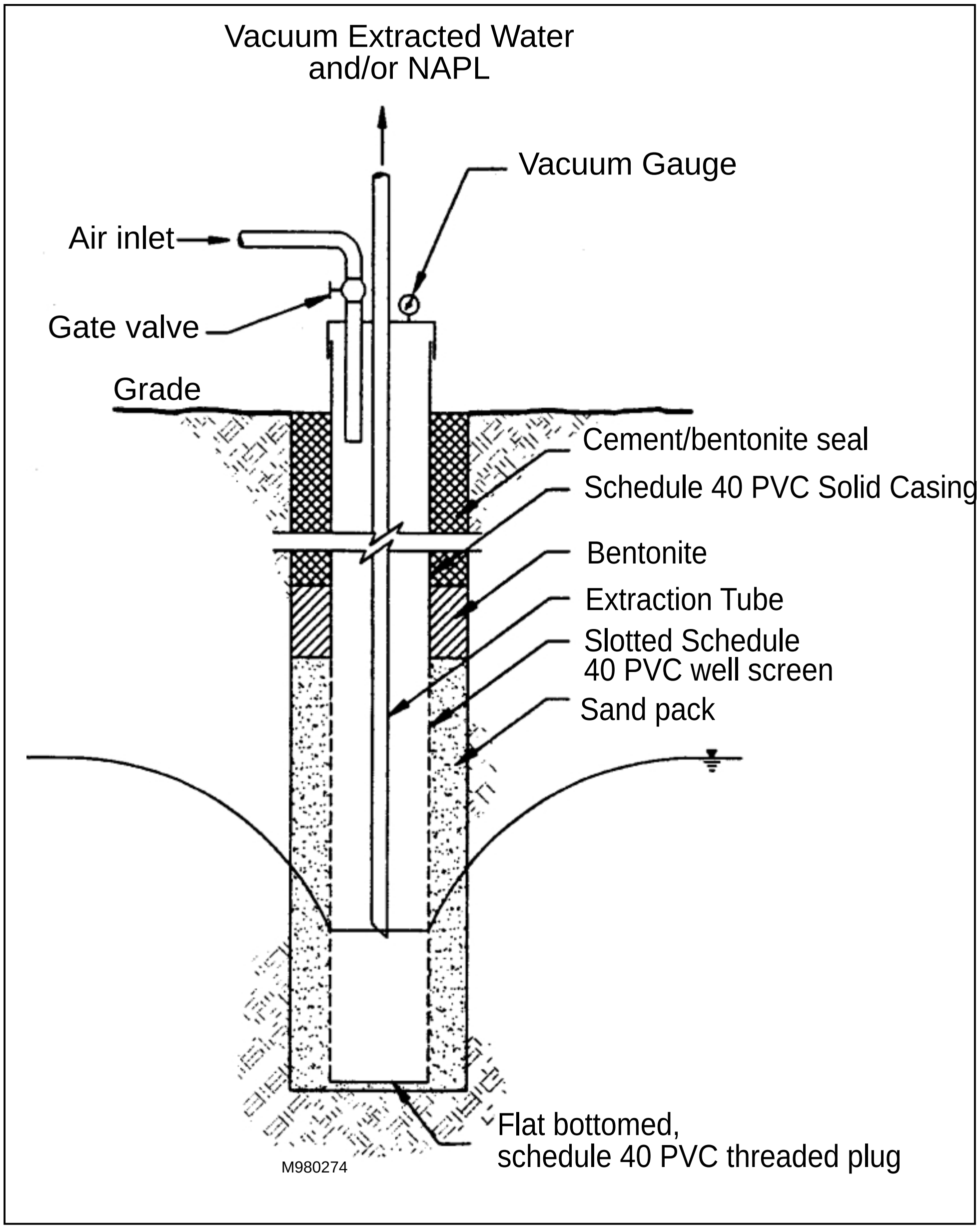


Figure 4-2. Two-Phase Extraction Well. (After EPA 1995)

(2) Mechanical System.

(a) Several mechanical systems are currently available for performing MPE pilot tests. DPE systems usually involve a submersible pump that removes water from the MPE well and an above-ground blower that removes gas from the MPE well. Liquid and gas streams extracted from the well are discharged in separate conduits to their respective treatment processes. Figure 3-7 illustrates a typical DPE system set up.

(b) TPE systems used for pilot tests are typically skid-mounted for ease of transport between sites. These systems involve a vacuum pump or blower (e.g., liquid ring pump, rotary vane pump), which draws liquid and gas through a single conduit located in the MPE well. The liquid is then separated from the gas above ground in a moisture separator that is connected to the appropriate treatment processes. Figure 3-8 and 4-3 show a typical layout and process flow diagram, respectively, for a TPE system. Example piping and instrumentation diagrams (P&IDs) can be found in Chapter 5.

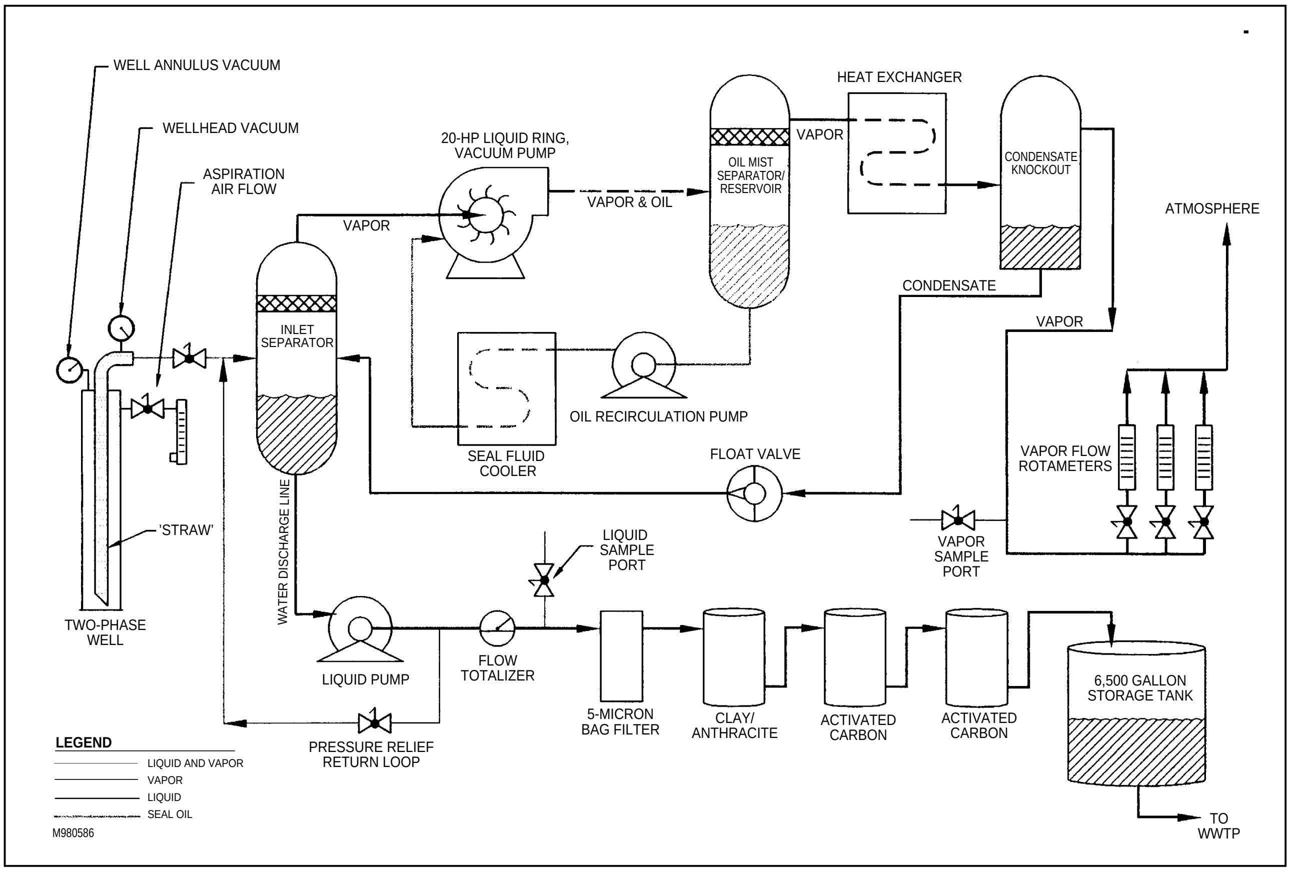


Figure 4-3. Process Flow Diagram of TPE Pilot Study Equipment (Radian International 1997)

(3) Treatment System. Depending on the contaminant of concern at the pilot study site and the duration of the pilot test, treatment for the liquid and gas streams may be required. Extracted liquid is typically routed through a NAPL/water separator, where NAPL, if present, is removed and stored in a dedicated tank. This is the case for either LNAPL or DNAPL, although separation of LNAPL is far more common. Water is pumped from the NAPL/water

separator and treated using an appropriate process (e.g., carbon adsorption) prior to discharge. Another option during a short-duration pilot test is to store extracted liquids temporarily in a tank (e.g., fractionation tank) and have the contents removed and treated off-site at the end of the test. Due to the high extraction velocity of liquid during TPE, there is a tendency for water and NAPL to form emulsions. This can have an impact on the selection of equipment used for treatment of extracted liquid, as more elaborate measures (e.g., polymer addition) may be required to separate the emulsion. Extracted gas may also require treatment depending on local air emission regulations and expected off-gas concentrations. Typically, vapor phase activated carbon or a catalytic or thermal oxidizer is used to treat extracted gas prior to its discharge to the atmosphere.

(4) Monitoring Points.

(a) Monitoring points used for measuring subsurface response to MPE must be strategically placed surrounding the MPE well. A typical configuration of monitoring points is at varying distances from the MPE well and along 90°, 120°, or 180° radials from the extraction well depending on variability of subsurface soils and budgetary constraints. This placement offers an improved likelihood of obtaining representative data points compared to installation of all points along the same radial, in which case it is possible that all may fall in a zone that is unrepresentative of the subsurface formation. Further information on placement and installation of monitoring points can be found in EM 1110-1-4001, Soil Vapor Extraction and Bioventing, Chapter 4, Bench- and Pilot-Scale Testing for SVE and BV, and Peargin and Mohr (1994).

(b) MPE monitoring points are typically installed as nested pairs of piezometers, one shallow and one deep. The shallow point is used to monitor changes in vadose zone gas pressure and gas concentration (e.g., oxygen, when an objective of the remediation is to enhance aerobic biodegradation of contaminants), and the deep point is used to monitor water table elevation and LNAPL thickness changes, if applicable. Existing monitoring wells screened across the water table (i.e., in the saturated and vadose zone) can be converted to monitoring points using compression seals. Care must be taken, however, to seal the tops of all monitoring points from the atmosphere to prevent short-circuiting of air. This is typically done by installing a valve at the top of the monitoring point that is normally closed but can be opened when a measurement is taken. In addition, monitoring points having narrow (discrete) screen intervals are preferable over those with long screen intervals, because the latter are more apt to intercept preferential flow pathways and thus reflect conditions within such pathways, rather than within the soil matrix. Deep monitoring point screens, however, must, be long enough to cover expected changes in water/LNAPL levels. Monitoring points may also include neutron probe access tubes to enable monitoring of changes in liquid saturation. Monitoring strategies for MPE pilot tests are similar to those used during SVE. A discussion of SVE monitoring strategy can be found in EM 1110-1-4001, Soil Vapor Extraction and Bioventing, Chapter 4.

e. Pilot Test Monitoring Methods.

(1) Above-ground Vacuum and Fluid Flow.

(a) Above-ground vacuum. Measurements for above-ground vacuum are typically taken in two places: at the MPE well head and at the inlet to the above-ground pilot system equipment (e.g., immediately upstream of the gas/liquid separator). The vacuum difference between the extraction equipment and the well head provide an indication of the pressure drop over the conveyance piping. Vacuum measurements taken at the well head give an indication of the vacuum being applied to the vadose zone. However, the vacuum applied at the drop tube or well head may be significantly different than the inlet vacuum, because much of the vacuum applied to the drop tube or well head is lost due to the energy expended in lifting liquid from the well and due to piping friction losses. These losses can vary significantly depending on the type and size of equipment used. As an example, a low capacity vacuum pump used in a moderately permeable soil may produce a high water/air ratio. This is because a high water production is obtained from the formation, which causes the drop tube (in TPE) to be mainly filled mainly with water, causing low airflow. The resulting high line loss due to the lifting of water can cause, in turn, a low applied vacuum on the subsurface (Peargin 1998). In this case, it may be more viable to use DPE rather than TPE, since, in order to make the latter successful, a higher capacity vacuum pump that can handle the extracted water, along with producing significant airflow, may be required, increasing costs significantly. The vacuum measurement at the aboveground equipment will give data indicative of the amount of vacuum that the vacuum pump or blower must be capable of producing to achieve the desired results. However, it is typically more useful to know what the vacuum at the well head is (rather than at the pilot system), in order to determine the size of the blower/pump that will be required for full-scale operation. It should be noted that there are various ways to adjust the applied vacuum, such as opening a dilution or ambient air intake valve to adjust the applied vacuum along the blower curve, or using a variable speed drive (refer to paragraph 5-6f(8). Variable speed drives allow more flexibility because the vacuum can be adjusted over a blower area (i.e., a set of vacuum versus flow curves that ranges over various frequencies of operation) rather than just along a single vacuum versus flow curve.

(b) Above-ground gas flow rate during TPE. Measurement of the extracted gas flow rate is performed using appropriate measuring devices during TPE. Measurement of gas velocity is typically performed using a Pitot tube, hot-wire anemometer, venturi meter, or other appropriate device positioned downstream of the point where liquid is removed from the extracted gas stream. Measurement of the flow of dilution or bleed-in air must also be made in order to calculate subsurface airflow and, depending on where measurements are taken, the mass of contaminant removed (paragraph 4-2e(3)). Due to the high vacuum applied to the gas stream (or high pressure and possibly temperature if flow measurements are taken on the positive side of the blower), gas flow or velocity measurements must be corrected to standard temperature and pressure conditions in order to make data comparisons. Measurements can also be corrected for relative humidity. However, this is generally not necessary because flow corrected for humidity is usually within one percent of the uncorrected value.

(c) Above-ground liquid flow rate during TPE. Measurement of extracted liquid flow is performed by measuring the volume of liquid that is discharged from the gas-liquid separator over a given time interval (e.g., recording the flow rate of water pumped from the separator). It should be noted that the above listed methods of measuring gas and liquid flow are applicable after the multi-phase streams from individual TPE wells are combined into a single multi-phase stream, and later separated into the component single-phase streams. During TPE, it is not practical to measure flow of gas and liquid from individual wells, due to the impossibility of isolating these two streams within the same conduit. It can be of value, however, to make qualitative observations of the relative proportion of gas versus liquid flow in a transparent section of the lateral from each well.

(d) Above-ground fluid flow during DPE. During DPE, measurements should be taken from both individual wells and from the combined gas and liquid streams emanating from multiple wells. This is possible because liquid and air are extracted in separate conduits. Again, when gas flow measurements are made, the dilution airflow must also be measured, and measurements must be adjusted to standard conditions.

(2) LNAPL Recovery.

(a) Instantaneous LNAPL recovery rates are difficult to measure because most sites do not produce a large enough volume of NAPL. Total accumulated LNAPL volumes can be measured easily depending on the type of pilot system used. In a typical system, LNAPL drains from the LNAPL/water separator into a storage tank. LNAPL volume can be measured from this storage tank with a sight glass or by recording the total volume of LNAPL each time the product storage tank is pumped. The volume of LNAPL recovered should be measured at least daily during pilot tests.

(b) In cases where emulsions form from the high velocity created by the pump, especially in diesel fuel applications, NAPL volumes can be estimated based on the concentration of the NAPL present in the emulsion (Keet 1995).

(3) Contaminant Mass Removal. Contaminant mass removal is calculated by multiplying the flow rate of gas or liquid extracted from the subsurface by the corresponding contaminant concentration in the gas or liquid stream. Whenever possible, measurements of gas contaminant concentrations should be taken from the same location (i.e., same side of the vacuum pump) as the flow measurement, although mass calculations can still be made if gas flow rates are corrected for dilution factors and standard conditions. Samples of both gas and liquid should be obtained (if possible) from their associated stream prior to contact with pilot test equipment. This will prevent cross-contamination from residue remaining within the equipment from previous pilot tests. This can be especially difficult in the case of the liquid stream, because the water and NAPL remain in a combined stream until after the NAPL/water separator. In this case, the separator should be properly decontaminated, or the sample should be taken from the MPE well.

(4) Vacuum Influence (Unsaturated Zone).

(a) Vacuum influence within the unsaturated zone can be monitored using soil gas probes connected to differential pressure gauges, which measure the difference between the pressure applied to the gauge and atmospheric pressure (i.e., they read “gauge” pressure). These readings, along with knowledge of the effective air permeability, are often the principal indication of the zone of influence (ZOI) surrounding an MPE well. Explanations of why ZOI, defined as the zone of effective air exchange, is preferable to reliance on the radius of pressure influence are given in EM 1110-1-4001, Soil Vapor Extraction and Bioventing, Chapters 4 and 5. The procedure used to calculate the flow velocity between monitoring points and the pilot test extraction well is given in Soil Vapor Extraction and Bioventing EM 1110-1-4001, Chapter 4. This velocity can then be used to estimate travel time (EM 1110-1-4001). The designer must determine, based on the site and cleanup objectives, what a reasonable travel time will be in order to meet these objectives. In the case where several wells are used for extraction during MPE pilot tests, modeling may be required in order to make a determination of the zone of influence.

(b) Changes in soil gas pressure in the vadose zone can also result from barometric pressure changes. Rising or falling barometric pressure caused by the passage of weather systems, for example, should be noted and considered in the interpretation of minor changes in subsurface vacuum. Barometric pressure can be measured using a portable instrument, or a record of local data can usually be readily obtained from a nearby meteorological station.

(c) Installation of soil gas monitoring points in silty-clay and clayey soils using direct push technology may have a tendency to result in smearing of the soil that is in contact with the probe. When sealed in this way, the soil can appear to be less transmissive than it actually is. Soil gas monitoring points installed with drill rigs can sometimes have faulty (i.e., leaky) well seals, whereby the soil can appear to be more transmissive than it actually is. A brief round of pressure testing of each monitoring point, regardless of method of installation, is recommended before the pilot test (to ensure its integrity and ability to transmit an adequate amount of airflow) and again after the pilot test (to determine whether desiccation cracks have changed its integrity). Pressure testing of this type is described in Peargin and Mohr (1994). Example results obtained from pressure testing of 6 shallow piezometers installed to depths of approximately 3 feet (1 m) bgs at the Lake City Army Ammunition Plant (LCAAP) indicated that three of the piezometers showed high air permeability with applied pressure dissipating into the formation in 8 seconds or less. Two of the piezometers showed low air permeability with pressure remaining in the piezometer after 60 seconds. One piezometer appeared to be clogged, with pressure of 60 kPa (9 psi) versus initial pressure of 68 kPa (10 psi) remaining in the probe after 460 seconds (Radian International 1997).

(d) Measurements of vacuum influence, coupled with measurements of applied vacuum and airflow at the MPE well, can be used with an appropriate solution to calculate the effective air permeability at the prevailing moisture content of the soil. For guidance on performance of such tests, see EM 1110-1-4001, Appendix D.

(5) Drawdown and Upwelling.

(a) The response of the water table to MPE is an important indication of the influence of MPE on the saturated zone. Drawdown is monitored by placement of pressure transducers at fixed depths in monitoring wells screened across the water table. Drawdown is the hydrostatic head measured at such transducers prior to MPE, less that measured during MPE.

(b) Measurements of drawdown, coupled with measurements of liquid flow, applied vacuum, and elevation head at the pump inlet, can be used with an appropriate analytical solution to estimate the transmissivity of that portion of the formation that is intersected by the well screen.

(c) Note that drawdown measurements indicate the position of the piezometric surface; they do not necessarily suggest that the soil above that surface is unsaturated or dewatered. Liquid saturation in the soil above the water table is governed by the capillary pressure that results from the vacuum being applied to the soil, relative to its capillary pressure-saturation relationship. Any pressure device used to monitor the degree of upwelling in the vicinity of an MPE well must be zeroed to the vacuum in the soil gas rather than to atmospheric pressure at the ground surface (In Situ, Inc. 1993; EM 1110-1-4001, Soil Vapor Extraction and Bioventing, Chapter 4). Refer to paragraphs 2-5e and 4-2e(4). By contrast, the vacuum applied to the subsurface does not affect the piezometric surface, because any additional head of water above the pressure transducer (resulting from upwelling) is reduced by the vacuum being experienced above the water table. In vacuum as in non-vacuum applications, the piezometric head at any point below the water table is, by definition, simply the difference between the pressure side of a differential transducer positioned at that point and atmospheric pressure. Figure 4-4 displays the piezometric surface in a two-phase and dual-phase extraction well where MPE is applied. Note that the gauge pressure, P_w, observed at the pressure measurement point is the height of the water column above the measurement point, less any applied vacuum experienced above the water. The gauge pressure at any point in the formation is zero (i.e., the pressure is in equilibrium with atmospheric pressure) if, and only if, the height of the water column above that point is equal and opposite to the vacuum being experienced in the vadose zone above the water. This set of points is the piezometric surface.

(6) Monitoring Saturation.

(a) It is highly useful to monitor soil moisture content (or liquid saturation) during MPE pilot tests, and thereby be able to better understand the degree to which the technology is able to dewater the soil and enhance airflow. Although soil samples could be collected for gravimetric determination of moisture content, implementation of a repeatable, non-destructive technique such as neutron thermalization is strongly recommended for this purpose. Its use in this respect is referenced in EM 1110-1-4005, Chapters 3 and 4.

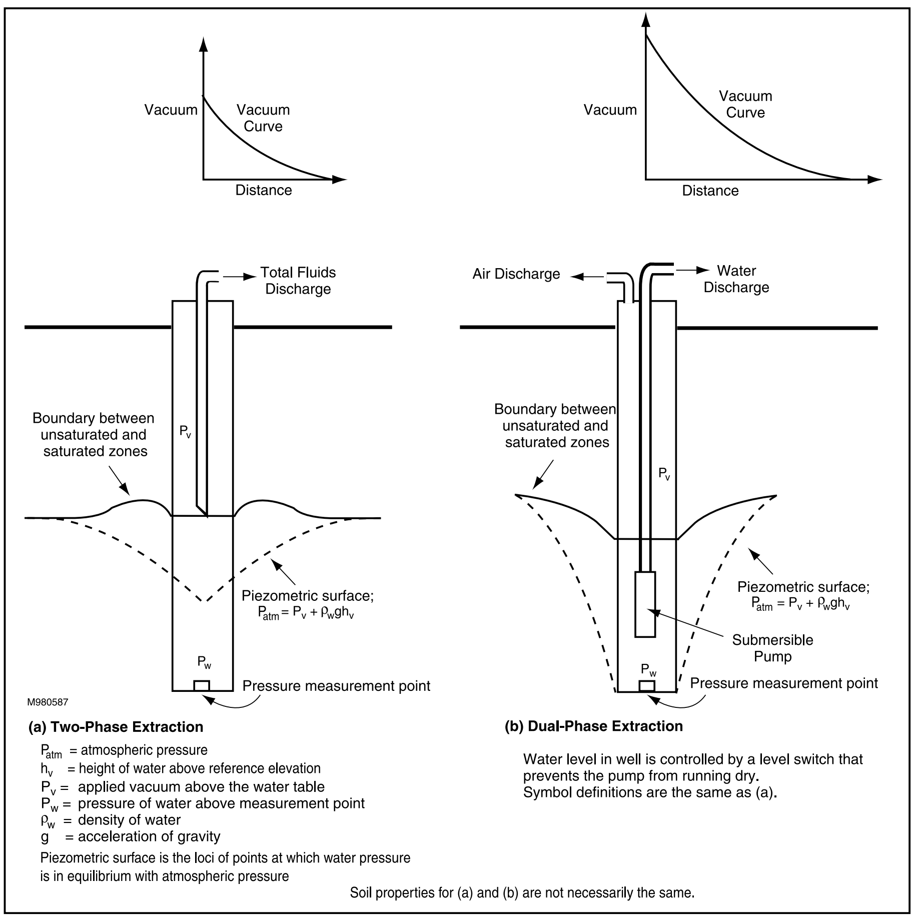


Figure 4-4. Piezometric Surface Under Application of MPE. (See paragraph 5-2e(5))

(b) Installation of neutron probe access tubes extending to the elevation of the bottom of the MPE well screen, at several locations within each pilot test area, plus at one or two locations beyond the expected ZOI of the pilot tests, enables soil moisture content to be profiled prior to and several times during an MPE pilot test. The neutron probe detects liquid content over a volume that extends approximately 20 to 50 cm (8 to 20 inches) out into the formation beyond the radius of the access tube itself. Thus the device measures the in-situ liquids content and indicates where the capillary fringe is located and where airflow is possible. Where both water and NAPL are present, since both are hydrogen-rich, they are indistinguishable by the device, which is sensitive to hydrogen content. Nevertheless, it does provide an accurate measure of total liquids content (i.e., saturation), and by subtraction from the initial, pre-MPE liquids content (which we may presume is fully saturated below the capillary fringe), indicates the air-filled porosity caused by MPE. Figure 4-5 presents saturation data obtained for two MPE pilot tests conducted at separate operable units at LCAAP (Radian International 1997; Baker and Groher 1998). Other techniques such as time domain reflectometry (TDR) can also be used to determine changes in soil moisture content (Clayton et al. 1995).

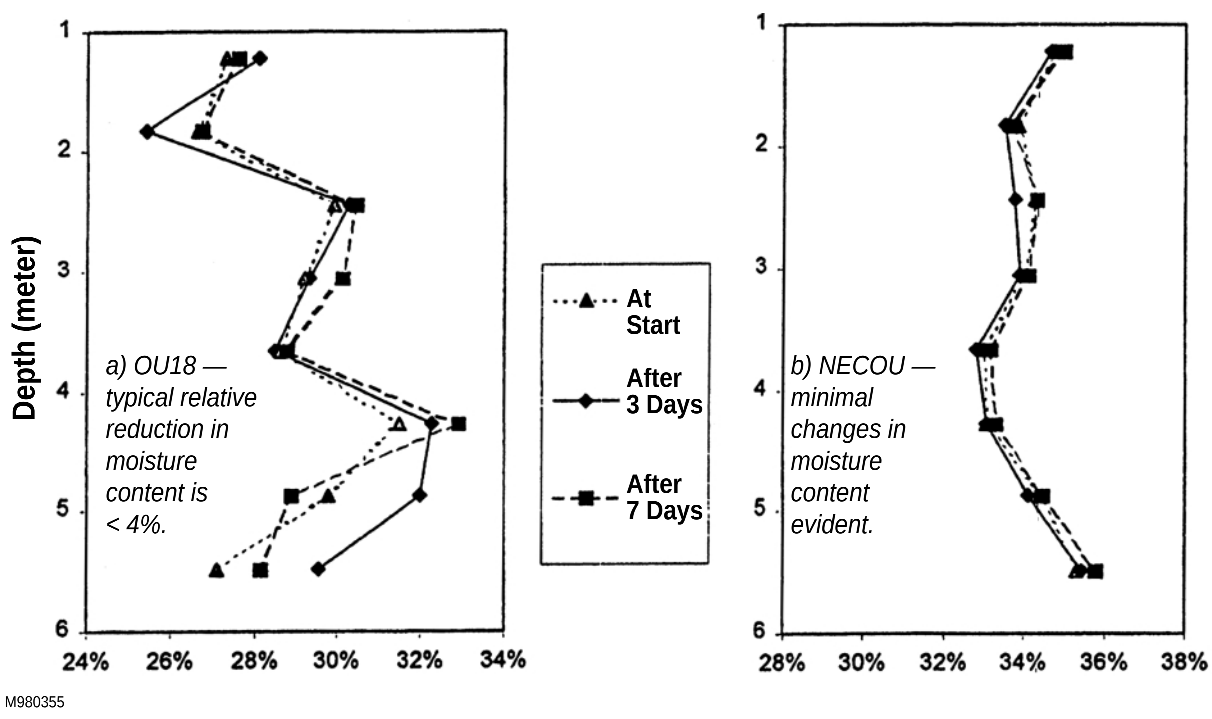


Figure 4-5. Moisture Profiles at LCAAP a) 4 ft (1.2 m) from the OU18 MPE well, and b) 5 ft (1.5 m) from the NECOU MPE well. (Radian International 1997; Baker and Groher 1998. Reprinted by permission of Battelle Press. Copyright 1998. All rights reserved.)

(c) Care should be taken, during installation of the neutron probe access tubes, to avoid changing the density and thus the moisture-holding characteristics of the soil within the zone that will be sensed by the neutron probe. Either increases (due to compaction resulting from driving a probe) or decreases (resulting, for example, from collapsing the formation against the tube) are undesirable and should be avoided to the extent possible. A recommended technique appropriate for fine-textured, non-stony soils is to use drill casing (preferably 2-inch diameter) to pre-bore a hole the same diameter as the access tube via drive and wash methods, after which the carbon steel access tube can be pushed directly into the boring.

(d) Soils targeted for MPE are typically medium and/or fine in texture. It may not be possible to desaturate such soils to a substantial extent. Recent research, including results from several USACE pilot tests, indicates that silty-clay and clay soils will resist undergoing any significant desaturation during MPE (Baker and Groher 1998).

(e) Capillary pressure-saturation curve measurements can be used both to estimate the ability of MPE to desaturate soil and to help explain the results of MPE pilot tests (Baker and Groher 1998). It is recommended that a representative number of intact soil cores be collected during the installation of the MPE wells, neutron access tubes, and/or adjacent monitoring points at depths representative of zones that are targeted for dewatering. Bulk density (ASTM 2850) and grain size distribution (ASTM D422) should be determined for each core as quality assurance measures. Capillary pressure-saturation curves provide an indication as to what level of vacuum, at equilibrium, needs to be exerted within the formation to reduce the water saturation to a desired degree. It may not be feasible to exert a high enough vacuum on fine-textured soils, because capillary forces tend to hold water in such soils so tenaciously. However, if pilot test data shows that the soils can be dewatered to some degree, these data can be used to evaluate the feasibility of dewatering over an expanded area during full-scale remediation. In addition, such data, if collected more widely from other locations within the site, can provide a way to extrapolate the results from pilot test locations to additional prospective MPE locations.

(7) Use of Tracers. Tracer gas tests employ gases not naturally occurring in unconsolidated sediment, such as sulfur hexafluoride or helium, to indicate rates of subsurface gas flow. Ideally, the selected tracer gas closely approximates the aggregate physical and chemical characteristics of the major compounds present in air, such as their solubility and density (molecular weight). During an MPE pilot test, tracer gas may be injected at one or more soil gas monitoring points. Equipment required is described in EM 1110-1-4005, Chapter 4. In the case of MPE, samples would be collected downstream of the gas-liquid separator at a location where airflow, temperature, and vacuum are also being monitored. The resulting record of tracer concentration as a function of time can be interpreted to indicate the spatial distribution and velocity of subsurface airflow resulting from MPE, and can indicate whether or not preferential flow is dominating subsurface airflow.

f. Reports.

(1) In order to develop a useful report for use during full-scale design, appropriate data must be collected in the field. It is important to consider the main objectives of the MPE application in order to ensure collection of the proper field parameters. Based on whether the main objective of MPE is to

enhance NAPL recovery, SVE or BV, or groundwater recovery, there are different parameters the pilot system operator should be observing. These parameters will also vary depending on whether a two-phase or dual-phase mode MPE operation is being employed. Table 4-1 displays required parameters to obtain during TPE and DPE applications based on which of the three main objectives the operation is based on (i.e., enhance NAPL recovery, SVE/BV, or groundwater recovery).

TABLE 4-1

Data Collection and Purpose of Collection During MPE Pilot Tests

	Two-Phase Extraction			Dual-Phase Extraction			
Goal / Parameter	**LNAPL Recovery**	**SVE/BV**	**GW Recovery**	**LNAPL Recovery**	**SVE/ BV**	**GW Recovery**	**Uses/Comments**
Gas phase mass removal		X			X		Increase at higher applied vacuum is favorable
Extracted LNAPL/water ratio	X			X			Observe ratios at different applied vacuum settings
Groundwater extraction rate	(X)	(X)	X	(X)	(X)	X	Increase at higher applied vacuum is favorable
Drop tube depth setting	X	X	X				Observe change in recovery rates at varying depths
Water table elevation changes	X		X	X		X	Indication of zone of pumping influence. Depression may increase gravity gradient for LNAPL flow to well.
Vadose zone pressure changes		X			X		Gives an indication of the zone of influence
Groundwater mass removal	X		X	X		X	Increase may indicate pumping from source area
O_2, CO_2, CH_4 in soil gas		X			X		Indication of biological activity in bioslurping applications
X = Required parameter **(X) = Optional parameter**							

(2) The data displayed in Table 4-1 are used to determine essential design parameters such as air permeability, hydraulic conductivity, and changes in saturation over time. Air permeability, along with zone of influence within the vadose zone (an especially useful parameter in cases of SVE enhancement) can be estimated as described in EM 1110-1-4001, Soil Vapor Extraction and Bioventing, Chapter 4 and Appendix D. Hydraulic conductivity is usually measured through standard hydraulic testing (e.g., pumping test, recovery test, slug test, etc.), although it may be possible to utilize data collected during an MPE pilot test to estimate hydraulic conductivity. In the enhanced-SVE MPE pilot test example that is presented later in this chapter (from Radian International 1997) the authors chose to employ, for that purpose, a mathematical solution for analysis of recovery test data. They adopted the assumption that any vacuum that existed in the formation during the MPE pilot test would dissipate quickly upon cessation of vacuum, and that they could therefore ignore any lingering vacuum effects and fit a hydraulic model to the distance-drawdown recovery data. Peargin and Mohr (1994) indicate it may take several months for vacuum to propagate into low permeability soil, much longer than the duration of a typical pilot test. This is illustrated on Figure 4-6.

One should nevertheless evaluate whether such an assumption is appropriate on a site-by-site basis.

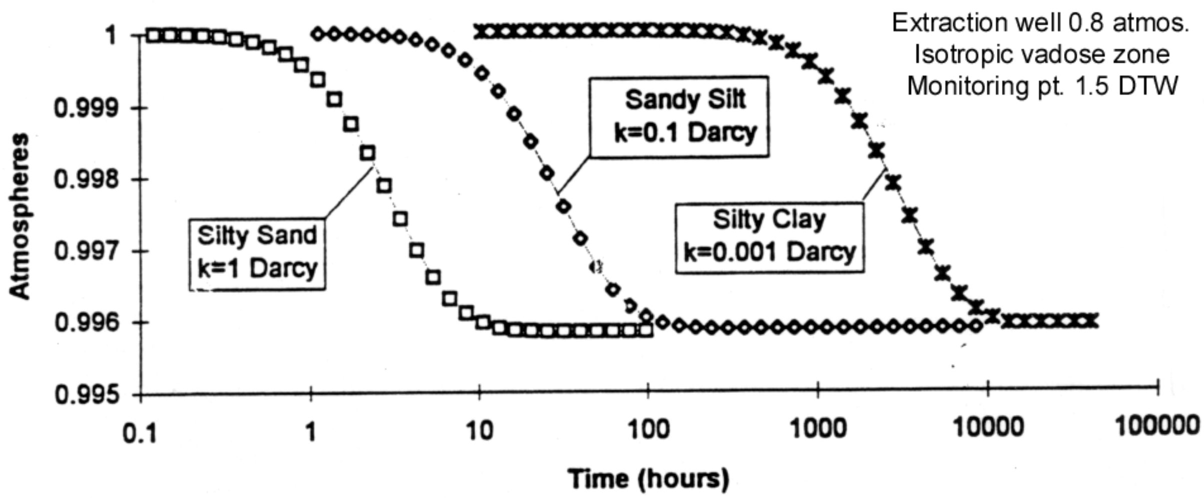


Figure 4-6. Transient Vacuum Propagation. (Peargin and Mohr 1994. Reprinted by permission of National Ground Water Association. Copyright 1994. All rights reserved.)
(DTW = depth to water table)

(3) Figure 4-7 is an example of a typical field data collection sheet for a bioslurping/MPE pilot test. Typical data collected include: recovered LNAPL volume, recovered air and water flow rate and contaminant concentrations (for calculation of mass removal), vacuum influence over distance from the extraction well, LNAPL thickness and groundwater elevation changes, and vadose zone oxygen and carbon dioxide concentrations (for indications of biological activity). Data collected from the field are typically tabulated in a spreadsheet program. Tables and graphs are then generated from the data to assist in evaluation of the effectiveness of the pilot study.

(4) Pilot study reports should include a summary of testing objectives and procedures, a summary and discussion of results, feasibility determination, and considerations for full-scale system design.

(5) Example tables and graphs from two separate pilot study reports are included as Tables 4-3 through 4-5 and Figures 4-8 through 4-12. Table 4-2 gives an overview of pertinent site information used in the example tables to give the reader a better understanding of the data presented and lists the tables and figures in this EM that display the pilot test results. The sites are a former industrial facility in Massachusetts and an Operable Unit (OU18) at Lake City Army Ammunition Plant (LCAAP) in Missouri.

BIOSLURPING/MPE TEST MONITORING SHEET

Facility Name ______________________ Location ______________________

Collector Name(s): ______________________

Conditions: ______________________

Date: ______________ Start Time: ______________ End Time : ______________

Vacuum Applied to System : ______________

Depth of Drop Tube: ______________

AMBIENT AIR INTAKE Flow : ______________ Temperature : ______________

TOTAL FLOW Flow: ______________ Temperature : ______________

GROUNDWATER TOTALIZER READING: ______________ gallons

VOLUME OF LNAPL RECOVERED: ______________

CUMULATIVE VOLUME OF LNAPL RECOVERED: ______________

PZ-1 Depth to Water: __________ Free Product: __________
Shallow: O2:__________CO2:__________Pressure : __________
Deep: O2:__________CO2:__________Pressure : __________

PZ-2 Depth to Water: __________ Free Product: __________
Shallow: O2:__________CO2:__________Pressure : __________
Deep: O2:__________CO2:__________Pressure : __________

PZ-3 Depth to Water: __________ Free Product: __________
Shallow: O2:__________CO2:__________Pressure : __________
Deep: O2:__________CO2:__________Pressure : __________

PZ-4 Depth to Water: __________ Free Product: __________
Shallow: O2:__________CO2:__________Pressure : __________
Deep: O2:__________CO2:__________Pressure : __________

PZ-5 Depth to Water: __________ Free Product: __________
Shallow: O2:__________CO2:__________Pressure : __________
Deep: O2:__________CO2:__________Pressure : __________

"Background" Monitoring Well Pressure : ______________

Blower Influent PID: __________ Carbon Midfluent PID: __________ Off-gas PID: __________

Comments/Observations: ______________________

____

M980283.eps

Figure 4-7. Example Field Data Collection Sheet.

TABLE 4-2

Overview of Example Sites

Parameter	Industrial Site (MA)	LCAAP OU18 (MO)
Primary Contaminants	TPH (mineral and heat transfer oil)	TCE, PCE, MIBK, toluene
Soil Type	Fill: boulders and cobbles, till, and bedrock	Alluvium: silty clay
Depth to Water Table (m bgs)	4.0	1.5
Extraction Well Screen Interval (m)	1.5 to 4.5	2.4 to 5.5
Extraction Well Diameter (cm)	10	10
Table/Figure Description	**Corresponding Table/Figure Number**	**Corresponding Table/Figure Number**
Operating Conditions Summary	Tables 4-3 and 4-4	Table 4-5
Cumulative Liquid Recovery	Figure 4-8	NA
Vacuum Influence at Monitoring Points	Figure 4-9[a]	Figure 4-10
Groundwater Elevation Changes	Figure 4-11[a]	Figure 4-12

Notes:
NA = not applicable
Information from MA industrial site from ENSR Corp. 1997
Information from LCAAP, MO site from Radian International 1997
[a]Vacuum influence and water level data from these figures taken from ENSR Corp. 1996 from the Squibb Mfg. Site, PR (data on this site are presented in Tables 4-6 and 4-7).

TABLE 4-3

Example Table (Fluid Data)

MA Industrial Site

Bioslurping/MPE Test: Groundwater/LNAPL Recovery Data

Source: ENSR Corporation 1997

Date	Time	Elapsed Time (hrs)	Applied Vacuum (inches Hg)	Total Fluids Extracted (gal)†	Extracted Emulsion			Free Phase LNAPL (gal)	Total LNAPL Recovered (emulsion + free phase) gal
					Flow Rate (gpm)	as LNAPL (gal)	as Water (gal)		
11/21/96	10:50	0.00	6.0	0.00	—	0.000	0.00	—	0.00
11/21/96	11:20	0.50	6.0	30.50	1.02	0.050	30.45	—	0.05
11/21/96	11:50	1.00	6.0	69.20	1.29	0.064	38.64	—	0.11
11/21/96	12:40	1.83	6.0	95.10	0.52	0.043	25.86	—	0.16
11/21/96	13:30	2.67	6.0	151.50	1.13	0.093	56.31	—	0.25
11/21/96	13:35	2.75	12.0	157.30	1.16	0.010	5.79	—	0.26
11/21/96	14:05	3.25	12.0	181.70	0.81	0.040	24.36	—	0.30
11/21/96	14:35	3.75	12.0	209.20	0.92	0.045	27.45	—	0.34
11/21/96	15:05	4.25	12.0	236.30	0.90	0.045	27.06	—	0.39
11/21/96	15:25	4.58	12.7	245.30	0.45	0.015	8.99	—	0.40
11/21/96	15:45	4.92	12.0	263.20	0.89	0.029	17.87	—	0.43
11/21/96	16:15	5.42	9.0	290.48	0.90	0.044	26.86	0.38	0.85
11/22/96	8:30	9.67	*	525.08	*	0.386	234.21	*	1.24
11/22/96	11:40	9.67	9.0	528.93	—	0.006	3.59	0.25	1.50
11/22/96	12:10	10.17	9.0	572.93	1.47	0.072	43.93	—	1.57
11/22/96	12:40	10.67	9.0	608.93	1.20	0.059	35.94	—	1.63
11/22/96	13:10	11.17	9.0	633.03	0.80	0.040	24.06	—	1.67
11/22/96	13:40	11.67	9.0	653.93	0.70	0.034	20.87	—	1.70
11/22/96	14:00	12.00	9.0	669.85	0.74	0.024	14.78	1.13	2.85
11/22/96	14:45	12.75	12.0	702.65	0.73	0.054	32.75	—	2.90
11/22/96	16:00	14.00	12.0	758.55	0.75	0.092	55.81	—	3.00
11/23/96	8:45	30.75	11.0	1315.15	0.55	0.916	555.18	0.50	4.41
11/24/96	10:20	56.33	10.9	2023.95	0.46	1.167	707.63	—	5.58
11/25/96	7:35	77.58	9.9	2535.58	0.41	0.843	510.76	0.03	6.45
11/25/96	10:50	80.83	10.7	2608.68	0.37	0.120	72.98	—	6.57
11/26/96	8:50	102.83	15‡	3186.38	0.44	0.952	576.75	0.13	7.64
11/26/96	10:05	104.08	shutdown	3305.68	1.59	0.196	119.10	0.38	8.22
Total volume recovered (gal):				3305.68	—	5.44	3297.96	2.78	8.22

Notes:

*System down due to high tank condition in oil/water separator at approximately 20:30 on 11/21/96. The system was restarted on 11/22/96 at 11:40.

†Based on totalizer readings. Evidence from emptying the fractionation tank indicates that totalizer may have been incorrect.

‡Increased applied vacuum on 11/26 believed to be caused by a rise in water table from rain and snow.

TABLE 4-4

Example Table (Air Data)

MA Industrial Site
Bioslurping/MPE Test: Air Flow/VOC Data
Source: ENSR Corporation 1997

Date	Time	Elapsed Time (hrs)	Applied Vacuum (inches Hg)	Depth of Slurp Tube (ft)	Ambient Air Intake (scfm)	Total Flow (scfm)	Flow from MW-25 (scfm)†	Blower Efluent FID Reading (ppmV)
11/21/96	10:50	0.00	6.0	12.7	44.4	53.7	9.3	—
11/21/96	11:20	0.50	6.0	12.7	39.8	52.8	13.0	—
11/21/96	11:50	1.00	6.0	12.7	38.1	53.1	14.9	3068
11/21/96	12:40	1.83	6.0	12.7	35.2	54.3	19.1	6157
11/21/96	13:30	2.67	6.0	12.7	35.2	54.0	18.8	6803
11/21/96	13:35	2.75	12.0	12.7	4.1	34.2	30.1	—
11/21/96	14:05	3.25	12.0	12.7	4.0	35.6	31.5	15880
11/21/96	14:35	3.75	12.0	12.7	4.0	35.8	31.8	14545
11/21/96	15:05	4.25	12.0	12.7	4.0	35.0	31.0	17759
11/21/96	15:25	4.58	12.7	12.7	0.0	31.0	31.0	—
11/21/96	15:45	4.92	12.0	12.7	0.0	31.8	31.8	14372
11/21/96	16:15	5.42	9.0	12.7	0.0	41.3	41.3	10121
11/21/96	20:30	9.67	*	*	*	*	*	*
11/22/96	11:40	9.67	9.0	12.8	—	—	—	—
11/22/96	12:10	10.17	9.0	12.8	32.0	47.0	15.0	2911
11/22/96	12:40	10.67	9.0	12.8	27.7	47.6	19.9	4510
11/22/96	13:10	11.17	9.0	12.8	26.8	48.7	21.9	4397
11/22/96	13:40	11.67	9.0	12.8	26.8	50.4	23.6	4493
11/22/96	14:00	12.00	9.0	12.6	26.8	50.4	23.6	—
11/22/96	14:45	12.75	12.0	12.6	4.0	39.0	35.0	—
11/22/96	16:00	14.00	12.0	12.6	0.0	36.6	36.6	9637
11/23/96	8:45	30.75	11.0	12.6	0.0	36.7	36.7	3193
11/24/96	10:20	56.33	10.9	12.6	0.0	40.2	40.2	3263
11/25/96	7:35	77.58	9.9	12.6	0.0	42.8	42.8	2940
11/25/96	10:50	80.83	10.7	14.3	0.0	39.6	39.6	3616
11/26/96	8:50	102.83	15‡	14.3	0.0	37.0	37.0	6017
11/26/96	10:05	104.08	shutdown	—	—	—	—	—

Notes: * System down due to high tank condition in oil/ water separator at approximately 20:30 on 11/21/96. The system was restarted on 11/22/96 at 11:40.
†Based on average groundwater extraction flow rates,
‡Increased applied vacuum on 11/26 believed to be caused by a rise in water table from rain and snow.

TABLE 4-5

Operating Conditions Data Summary for OU 18 Shallow Well Pilot Test (LCAPP). (Radian International 1997)

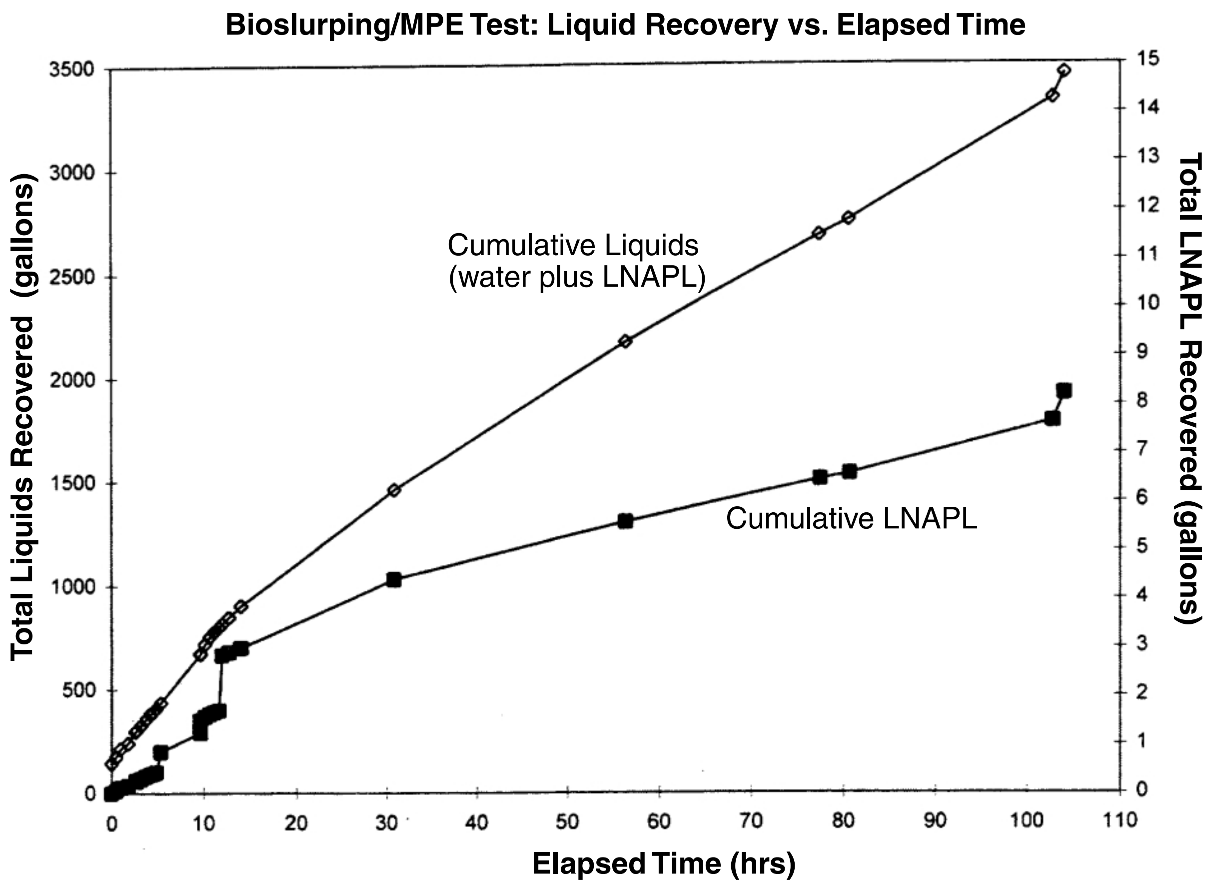
Actual Schedule			Pump Inlet Data		Wellhead Data				Exhaust Vapor		Cumulative Liquid Flow (gal)	Vapor Flow Rate (cfm)
Day	Time	Total Hours	Temp (°F)	Vacuum (in. Hg)	Straw Vacuum	Casing Vacuum	Annulus Vacuum	Aspiration Air Flow Rate	Temp (°F)	Pressure (psi)		
10/31/96	1550	0	36	0	0[a]	0	0	0	84	0	0	20
10/31/96	1615	0.25	40	22.5	14[a]	13.5	13.5	9	100	05	92.5	37
10/31/96	1700	1	40	24.2	14[a]	14.9	14.7	9	110	0.5	195.1	16
10/31/96	1800	2	40	23.8	13.75[a]	15.25	15	9.5	107	0.5	363.1	24
10/31/96	1900	3	40	24.5	14[a]	15.25	15	9.5	105	0.5	498.8	26
10/31/96	2000	4	40	23.5	13.5[a]	15.5	15.2	9.5	102	0.5	647.6	26
10/31/96	2200	6	40	23.5	14[a]	15.5	15.5	9.5	107	0.5	896.4	28
10/31/96	2400	8	40	23.5	14[a]	15.7	15.5	9.5	110	0.5	1,094.5	28
10/31/96	400	12	40	23	13.2[a]	15.5	15.2	9.5	105	0.5	1,503.7	26
10/31/96	1000	18	40	23.7	14[a]	15.4	15	9	114	0.5	2,057.9	34
10/31/96	1600	24	40	23	13.5[a]	14.9	14.5	9	113	0.75	3,041.3	37
10/31/96	2200	30	40	24	17[a]	19	18.5	0	110	0.5	4,485.6	23
11/1/96	400	36	40	23.5	16.2[a]	18.9	18.2	0	110	0.5	8,742.6[c]	24
11/1/96	1000	42	40	24	16.2[a]	18	17.2	0	112	0.5	9,853	25
11/1/96	1600	48	40	24.5	16.5[a]	17.5	17	0	112	0.7	10,544.9	30
11/1/96	2200	54	40	22.5	14.5[a]	16	15.5	0	110	0.75	10,899.2	35
11/2/96	400	60	40	22	13[a]	15	15.2	0	107	0.75	11,195.5	35
11/2/96	1000	66	40	22.5	14[a]	15.7	15	0	110	0.5	11,481.3	35
11/2/96	1600	72	40	23.7	18.5	15.6	N/A[b]	0	113	0.75	11,767.2	38
11/2/96	2200	78	40	21	17	14.5	14	0	119	1	12,025.2	42
11/3/96	400	84	40	21.2	17.5	14.7	14.2	0	113	1	12,275.2	41
11/3/96	1000	90	40	23	17.5	14.5	14.2	0	112	0.9	12,525.6	42
11/3/96	1600	96	40	21.2	14.5	10	10	0	125	0.8	12,762.2	56
11/3/96	2200	102	40	20.5	13.5	9.5	9	0	120	1	12,993	61
11/4/96	400	108	40	20	12.5	8.75	8.5	0	115	1	13,269.4	62
11/4/96	1000	114	40	20.5	N/A[b]	10.5	10	0	109	1	14,076	53
11/4/96	1600	120	40	22	16.5	13	12	0	115	0.5	13,825.2	39
11/4/96	2200	126	40	23	17	13.5	13	0	116	0.5	14,215.8	38

TABLE 4-5 (Continued)

Actual Schedule			Pump Inlet Data		Wellhead Data				Exhaust Vapor		Cumulative Liquid Flow (gal)	Vapor Flow Rate (cfm)
Day	Time	Total Hours	Temp (°F)	Vacuum (in. Hg)	Straw Vacuum	Casing Vacuum	Annulus Vacuum	Aspiration Air Flow Rate	Temp (°F)	Pressure (psi)		
11/5/96	400	132	40	22.5	16.5	13.5	13	0	112	0.5	14,652.4	37
11/5/96	1000	138	40	23.5	16	13.2	13	0	117	0.5	15,080.9	37
11/5/96	1600	144	40	23.5	16	13	12.9	0	118	0.5	15,461.1	39
11/5/96	2200	150	40	23	16	13	12.5	0	120	0.5	15,848.6	39
11/6/96	400	156	40	23.5	15.5	12.9	12.3	0	120	0.5	16,174.4	40
11/6/96	1000	162	40	24.2	15.2	12.5	12	0	122	0.5	16,311.3	40
11/5/96	Post-test (final)		NA	Na	Na	NA	NA	NA	NA	NA	16,322.5	NA

Notes:
[a]Vacuum gauge partially plugged. New gauge installed on 2 November 1996.
[b]Reading not taken
[c]This large increase in flow was due to excess recirculating of water through flow meter and back to inlet separator. Recirculation system was re-piped to address this problem. Flow rates during this interval were adjusted to reflect average of prior flow rates and subsequent flow rates.

cfm	=	cubic feet per minute
gal	=	gallon
in. Hg	=	inches in mercury
psi	=	pounds per square inch
NA	=	Not applicable
N/A		Not available



NOTE: Operational parameters associated with this figure are included in Table 4-3.
M980280

Figure 4-8. Example Graph (Liquid Recovery) MA Industrial Site. (ENSR Corp. 1997)

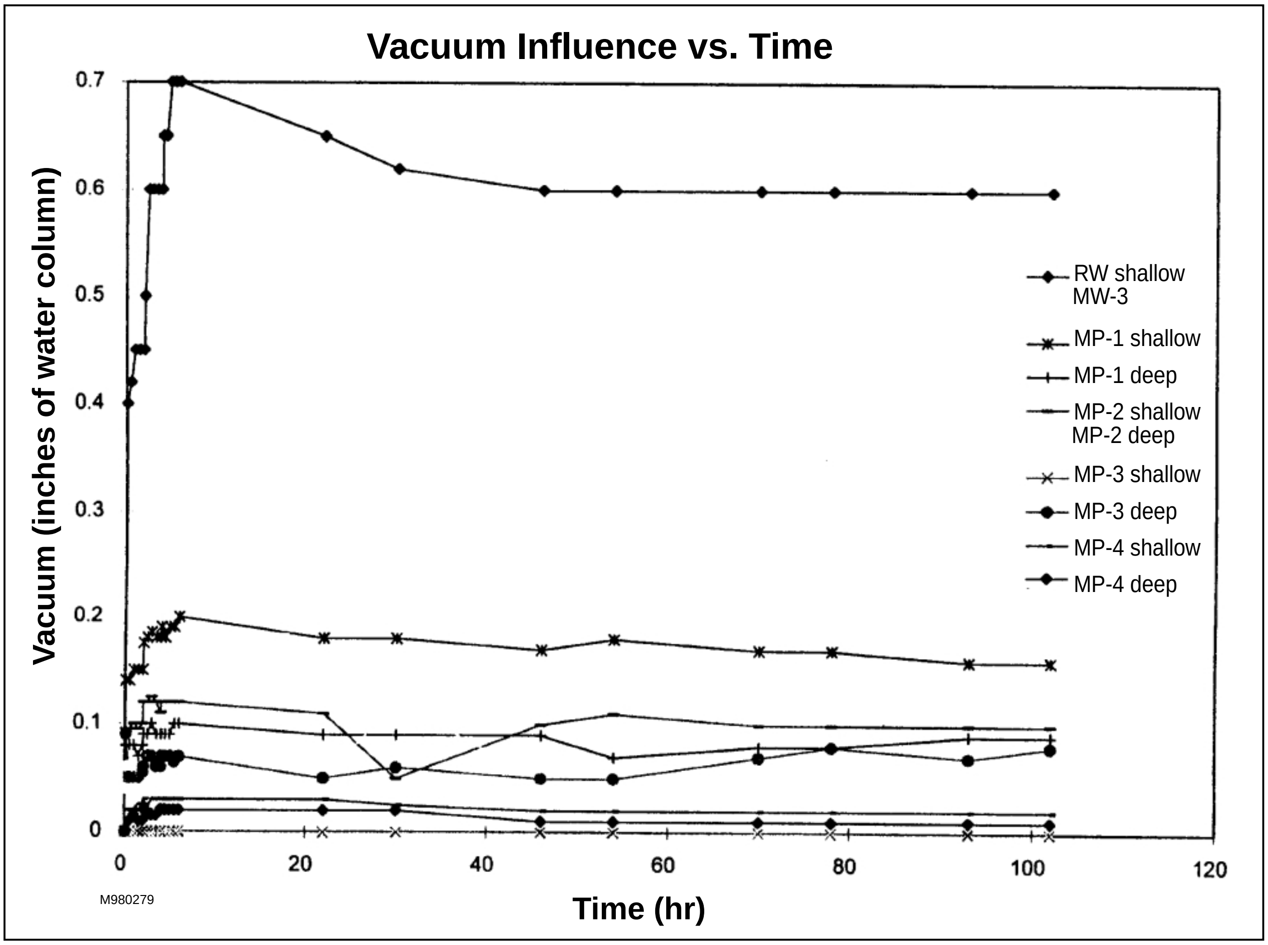


Figure 4-9. Example Graph (Vacuum Influence Data) Squibb Mfg. Site, PR. (ENSR Corp. 1996)

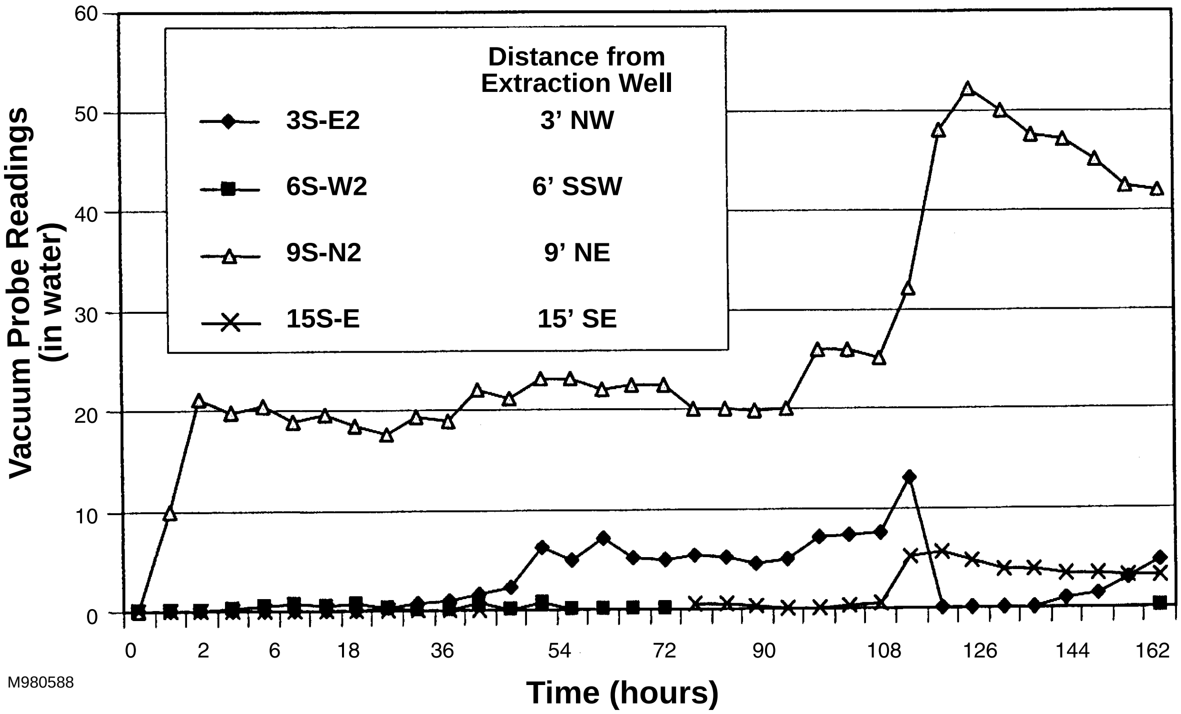


Figure 4-10. Example Graph (Vacuum Influence Data) LCAAP. (Radian International 1997)

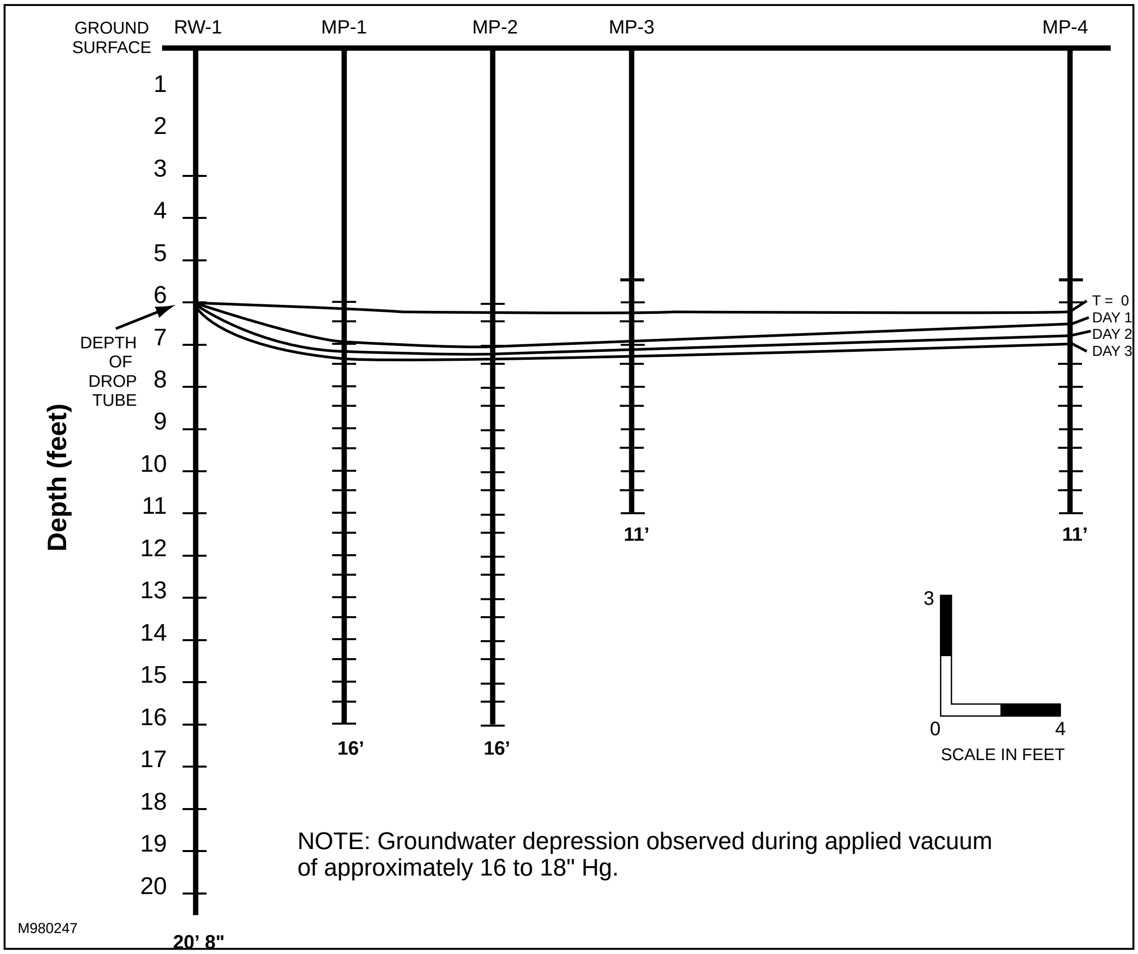


Figure 4-11. Example Graph: Groundwater Depression During Bioslurping Pilot Test Squibb Mfg. Site, PR. (ENSR Corp. 1996)

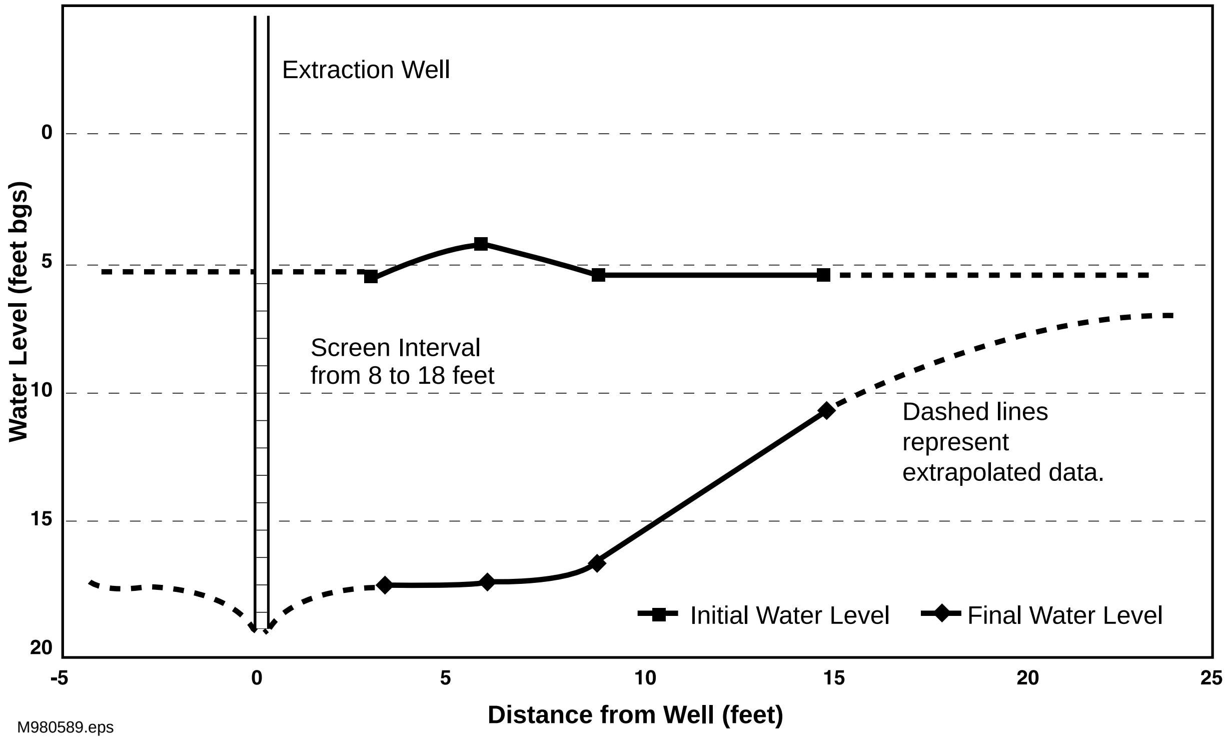


Figure 4-12. Example Graph: LCAAP Area 18 Shallow Well Pilot Test Groundwater Depression. (Radian International 1997)

(6) Further examples of key reporting parameters are summarized in Tables 4-6 and 4-7 (from Baker and Groher 1998; Radian International 1997; and FWEC 1997). These tables provide a comparison of data obtained from MPE pilot tests performed at chlorinated solvent contaminated sites. Additional studies have been performed by the Air Force Center for Environmental Excellence (AFCEE) at a number of MPE sites. Table 4-8 (Kittel et al. 1995) shows product recovery results at 10 AFCEE sites along with radius of influence and biodegradation rate data. Figure 4-13 (Kittel et al. 1995) shows product recovery versus time for an MPE pilot test performed by AFCEE.

4-3. Field Criteria for Evaluating MPE Feasibility Based on a Pilot Test. There is not a specific set of criteria by which to measure the success of an MPE pilot test, nor is there a single criterion that is “make-or-break”; rather there are various important lines of evidence that must together be weighed to reach an appropriate judgment as to the success of the pilot test.

a. If the purpose of MPE is to enhance NAPL recovery, the rate of NAPL recovery should be compared to that observed during conventional recovery without application of vacuum. AFCEE (1997) discusses how this technique can be utilized for determining the effectiveness of bioslurping based on a pilot test.

b. If the purpose of MPE is to enhance vapor extraction, the contaminant mass recovered in the gas phase should be compared to that recovered in the liquid phase. If the former exceeds the latter during the pilot test, it would be an indication that the technology is functioning as intended. In addition, gas phase mass recovered using SVE alone should be compared to that recovered using MPE. Table 4-7 (from Baker and Groher 1998) provides information on VOC mass extracted in the gas and liquid phases for several pilot tests. As the data indicate, all sites showed significantly more mass extracted in the gas phase compared to the liquid phase. In TPE applications, it should be noted that off-gas concentrations at sites containing contaminants that are more volatile may increase due to VOC partitioning from the liquid to gas phase. In these cases, an increase in gas phase mass removal may not be indicative of an improvement in TPE system performance. There remains the distinct possibility that at some point during the actual remediation, the contaminant mass recovered in the gas phase may decline and become less than that recovered in the liquid phase. Such a change would signal a loss in efficiency.

c. Determining Whether the Vacuum Influence within the Subsurface is Well Distributed as Indicated by Monitoring Point Data.

TABLE 4-6

MPE Pilot Test Site Conditions
(Baker and Groher 1998. Reprinted by permission of Battelle Press.

SITE	Primary Contaminants	Soil Type	Depth to Water Table ft (m) bgs	Extraction Well Screen Interval ft (m) bgs	Hydraulic Conductivity (cm/sec)
Squibb Mfg. Co. Site, Humacao, PR	Dichloromethane ($MeCl_2$), MIBK, xylenes	fill: clay	0.5 (0.15)	3 to 20 (0.9 to 6.1)	1×10^{-6} (a) 5×10^{-4} (b)
Confidential Site, S. CA	1,2-DCA, TCE, VC	silty sand, silty clay	20 (6.1)	20 to 30 (6.1 to 9.1)	3×10^{-7} (c) 4×10^{-5} (d)
LCAAP OU18, Lake City, MO	TCE, PCE, MIBK, toluene	alluvium: silty clay	5 (1.5)	8 to 18 (2.4 to 5.5)	9×10^{-6} (e) 2×10^{-4} (f)
LCAAP NECOU, Lake City, MO	TCE, PCE, toluene	residual colluvium: silty clay	7 (2.1)	5 to 26 (1.5 to 7.9)	2×10^{-7} (g) 3×10^{-5} (f)
Silresim Superfund Site, Lowell, MA	1,1,1-TCA, TCE, 1,1-DCE, Freon 113, $MeCl_2$, ethylbenzene, benzene, styrene	lacustrine: silts and sandy silts	5 (1.5)	11 to 32 (3.4 to 9.8)	4×10^{-5} to 1×10^{-3}

Laboratory determinations on: (a) 1; (c) undetermined number; (e) 8; and (g) 5 intact soil cores (mean is reported where applicable). Field determinations based on: (b) Mean of slug tests; (d) Numeric flow model calibrated to MPE test; (f) Modified pumping test conducted during MPE.

TABLE 4-7

**MPE Pilot Test Operating Conditions and Results
(Baker and Groher 1998. Reprinted by permission of Battelle Press.
Copyright 1998. All rights reserved.)**

SITE	Test Length (hr)	Applied Vacuum in. Hg (kPa)	SVE Rate scfm (std. m^3 per min)	GWE Rate gpm (L/min)	VOC Mass Extracted as vapor / as liquid	Test Designer/ Operator
Squibb Mfg. Co. Site, Humacao, PR	128 (1)	6-19 (20-64)	18 (0.5)	0.38 (1.4)	5 kg / < 1 kg	ENSR Corp.
Confidential Site, S. CA	160	4-8 (14-28)	25 (0.7)	0.07 (0.3)	1,360 kg / 900 kg	ENSR Corp.
LCAAP OU18, Lake City, MO	162	9-16 (31-54)	35 (1.0)	0.85 (3.2)	379 kg / 17 kg	Radian Int. LLC
LCAAP NECOU, Lake City, MO	162	16-24 (54-81)	2.4 (0.07)	0.15 (0.6)	70 kg / 0.5 kg	Radian Int. LLC
Silresim Superfund Site, Lowell, MA	64 (2)	7-25 (24-85)	2 (0.06)	0.8 (3.0)	12 kg / U	Foster Wheeler Env. Corp.

(1) Data are representative of MPE with drawdown phase of test (128 hr); bioslurping (i.e., MPE without drawdown) had first been conducted for 102 hr. (2) Data are representative of MPE with drawdown portion of test, conducted for 64 hr. High vacuum SVE had first been conducted for 72 hr. Following MPE, SVE with dewatering using submersible pumps was conducted for 456 hr. (U) indicates undetermined.

TABLE 4-8

Bioslurper Comparative Fuel Recovery Rates and Bioventing Feasibility Study (Kittel et al. 1995. Reprinted by permission of National Ground Water Association. Copyright 1995. All rights reserved.)

Base Location	Site ID	Average Fuel Recovery (gal/day)				Soil Gas Radius of Influence (ft)	Biodegradation Rate (mg/kg/day)
		2-Day Skimmer Test	4-day Bioslurper Test	1-Day Skimmer Test	2-Day Drawdown Test		
Bolling AFB, D.C.	Bldg. 18	16.9	59.8	8.2	31.2	45	NA
Bolling AFB, D.C.	Bldg. 41	0.86	1.14	NA	0.13	47	12.9 to 15.3
Andrews AFB, MA	Bldg. 1845	8.7	78.5	0.7	NA	250	21 to 7.5
Wright-Patterson AFB, OH	Well P6-2	4.0	4.65	NA	2.46	10.0	1.3 to 3.2
Travis AFB, CA	JFSA-1	0.0	3.85	0.0	3.76	55.3	61 to 82
Robins AFB, GA	UST 70/72	10.85	47.5	4.96	11.5	56	1.8-3.3
Robins AFB, GA	SS010	1.41	3.22	NA	0.36	76	6.9-10.7
Kaneohe MCBH, HI	POL Tank Farm	0.0	2.39	0.05	0.0	23	60 to 122
Hickam AFB, HI	Area H	34.5	90.9[1]	NA	408.5	NA[1]	5.1 to 21
Johnston Atoll DNA	Tank 41	29.8	56	3.6	9.5	15.0	3.9 to 8.0

NA Test not performed.
[1] Extraction well screen extended to the ground surface causing short-circuting.

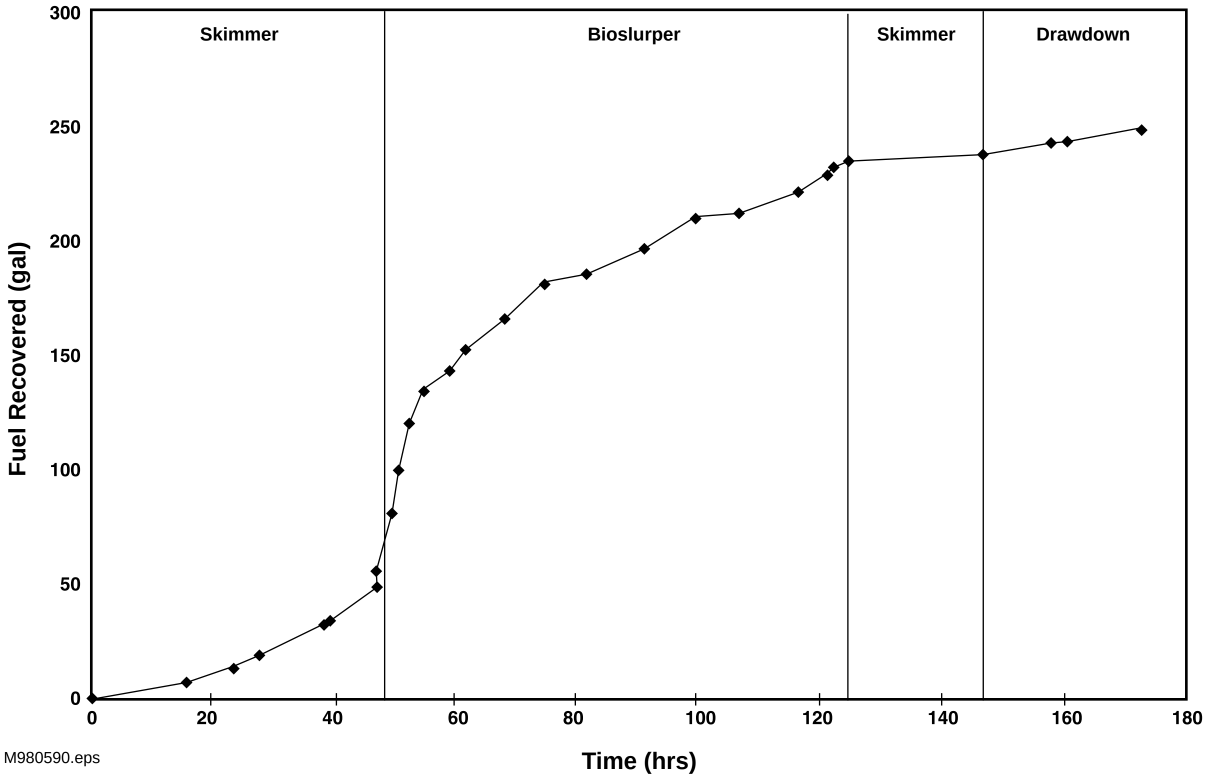


Figure 4-13. Example Graph: Fuel Recovery versus Time throughout the Bioslurper Pilot Test Performed by AFCEE at Johnston Atoll, Well JA-4. The four phases of the test are in accordance with the AFCEE Bioslurping Protocol. (Kittel et al. 1995. Reprinted by permission of National Ground Water Association. Copyright 1995. All rights reserved.)

d. Determining the Zone of Effective Air Exchange. Note that the conventional radius of influence (EM 1110-1-4001, Chapter 4) tends to overestimate the zone of effective air exchange because at the outer limits of the capture zone (i.e., where some arbitrarily small vacuum level may be detectable), the travel time to the MPE well will be unacceptably long. However, if the purpose of the applied vacuum is not to promote airflow in the vadose zone, but rather to enhance the total gradient driving water and/or product into the well, then a pressure radius of influence approach may be valid. The zone of effective air exchange, by comparison, is much smaller (Johnson and Ettinger 1994). If a goal of MPE is to promote bioventing, examination of oxygen distribution using subsurface monitoring points will yield an indication of the zone of influence.

e. Preferential flow may be present if any of the following conditions exist: 1) there is much more influence observed at one or two depths or directions relative to the MPE well than others; 2) there is more influence observed at a distant monitoring point than at closer points; or 3) there is no influence at a significant number of monitoring points that were pre-tested and determined not to be clogged. Preferential flow of air is not regarded as favorable for MPE unless such flow pathways contain a substantial contaminant mass (Baker and Groher 1998). If short-circuiting of air has been observed at the surface such as at the base of a well riser, it may be necessary to repair a surface seal or install a new MPE well. (Foams, such as shaving foam, can be used to detect such leaks; the foam collapses if air leakage under vacuum is occurring).

f. The efficiency of the extraction well, based on a comparison of the applied vacuum with that measured within an annular monitoring point (as described in EM 1110-1-4001, Chapter 4), must be identified in order to determine whether the well can be used for MPE and whether the pilot test produced unfavorable results due to an inefficient well.

g. On the basis of neutron probe measurements, the degree to which the soil was able to be dewatered or desaturated should be determined. If saturation values remain high within zones targeted for MPE, gas-phase mass transfer will tend to be very inefficient and mass transfer will have to occur mostly within the liquid phase. If NAPL recovery is a goal of the remediation, maintaining high NAPL saturations in extracted liquids should be pursued. If NAPL recovery is not a goal, however, the resulting predominantly liquid-phase mass transfer process will suffer from the same limitations that are common to pump-and-treat.

h. If inducement of subsurface airflow is an objective, the induced vacuums should be compared with the capillary pressure-saturation curves obtained from representative, intact soil cores. Specifically, it should be determined whether the air emergence pressure (paragraph 2-5e(5)(a) based on the soil cores was achieved at the various soil gas monitoring points during MPE.

i. The behavior of the free water surface should be measured within monitoring wells in order to determine if MPE controlled upwelling as intended, and to determine whether the extent of the groundwater zone of influence was satisfactory.

j. If the equipment did not operate as expected during the pilot test, operating malfunctions or problems may indicate design problems. Formation of emulsions that prove difficult to break can render vacuum-enhanced NAPL recovery problematic.

k. Calculations should be made as to what fraction of the estimated contaminant mass within the zone of effective air exchange was extracted during the pilot test. Although one should not expect a high mass removal over the short period of the pilot test (unless the goal is NAPL recovery and the NAPL plume is relatively small), it may be useful to estimate this fraction and judge how promising the technology is from the result.

l. Hydraulic parameters of the subsurface (e.g., hydraulic conductivity) and NAPL permeability estimates are important to obtain during pilot tests (see paragraph 4-2(f)(2).

m. If the pilot test had to be conducted for a longer period than originally intended due to specific reasons, they may suggest potential limitations to the applicability of MPE to the site.